The Electron-Ion Collider (EIC) Accelerator and Physics Program: The EIC as a bridge to FCC-ee

Wouter Deconinck, University of Manitoba

Future Particle Physics Energy Frontier Facilities

2026 CAP Congress

Maybe your institution's logo will be here next time… Talk to us!

Supported in part by NSERC SAPPJ-2021-00026, SAPPJ-2023-00041, SAPPJ-2025-00040, CFI-IF-45702.

Electron-Ion Collider: Science Pillars

How do quarks, gluons, and orbital angular momentum contribute to proton spin?

Spin is a fundamental property of matter. All elementary particles but Higgs carry spin.

Spin of composite particles such as the proton cannot be explained by a static picture but are caused by the **interplay of properties and interactions of quarks and gluons inside.**

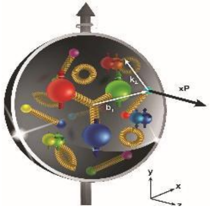
SPIN

Does the mass of visible matter emerge from quark-gluon interactions?

Atom:
Binding/Mass = 0.00000001
Nucleus:
Binding/Mass = 0.01
Proton:
Binding/Mass = 100

The EIC will determine an important term contributing to the proton mass, the **proton mass,** the so-called QCD trace anomaly.

MASS



How are quarks and gluons distributed in space and momentum inside the nucleon & nuclei?

How do the nucleon properties **emerge from them and their interactions?**

How can we understand their **dynamical origin in QCD?**

What is the relation to **confinement?**

3D-Imaging

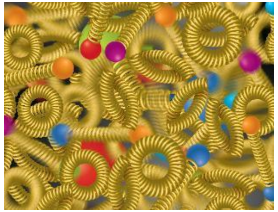
How do the confined hadronic states emerge from quarks and gluons?

Is the structure of a **free and bound** nucleon the same?

How do quarks and gluons **interact with a nuclear medium?**

How do the quark-gluon interactions **create nuclear binding**?

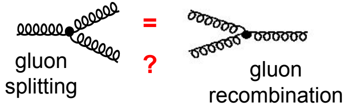
QCD in Nuclei



Does gluon density in nuclei saturate at high energy?

How many gluons can fit in a proton?

How does **a dense nuclear environment affect** the quarks and gluons, their correlations and interactions?

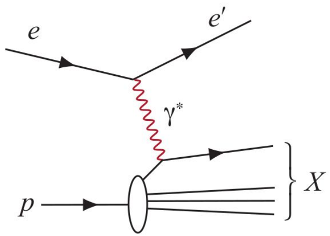


Dense Gluon Systems

Refs: National Academies, An Assessment of U.S.-Based Electron-Ion Collider Science; EIC Yellow Report

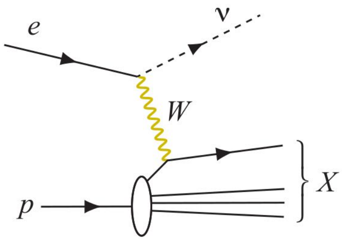
Electron-Ion Collider: Our Microscope

Deep inelastic scattering (DIS) event kinematics from scattered electron or final state particles (CC DIS, low y)



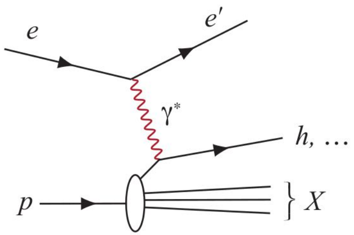
Neutral Current DIS

- Detection of scattered electron with high precision - event kinematics



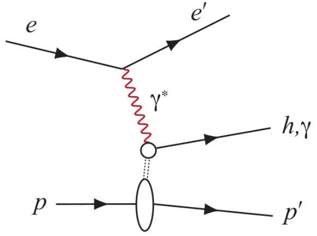
Charged Current DIS

- Event kinematics from the final state particles (Jacquet-Blondel)



Semi-Inclusive DIS

- Precise detection of scattered electron in coincidence with at least 1 hadron



Deep Exclusive Processes

- Detection of all particles in event, including scattered proton

NUCLEI

Parton Distributions in nucleons and nuclei

SPIN **IMAGING**

Spin and Flavor structure of nucleons and nuclei

Tomography Transverse Momentum Dist.

GLUONS **MASS** **IMAGING**

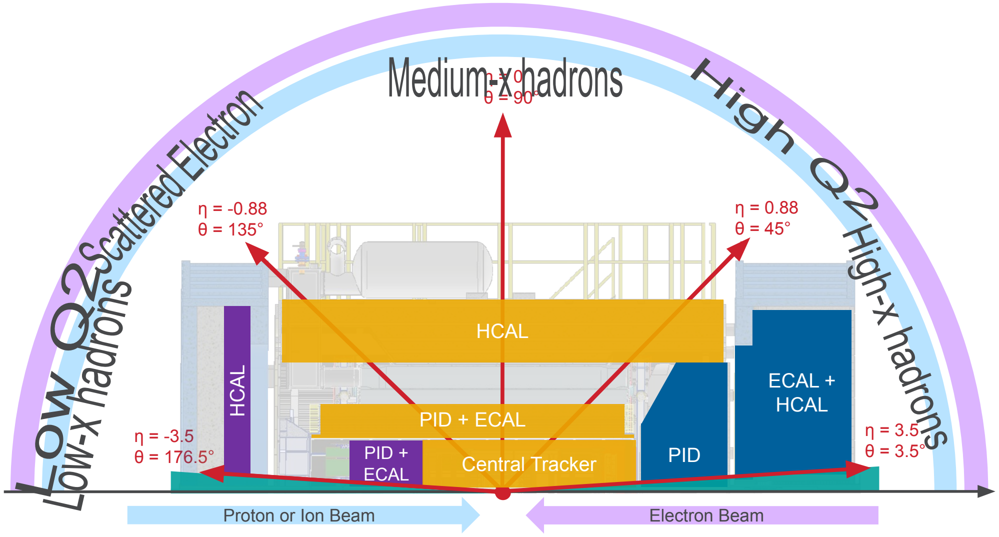
QCD at Extreme Parton Densities - Saturation

Tomography Spatial Imaging

Electron-Ion Collider: Accessing the Physics

Inclusive DIS requires fine binning in x_B, Q^2:

- Large angular coverage for wide phase space reach
- Excellent EM-calorimetry with PID support for e/π separation, and good electron energy resolution
- Fine resolution tracking with low mass



Semi-inclusive DIS requires binning in five or more variables (x_B, Q^2, z, p_T, φ_h , …):

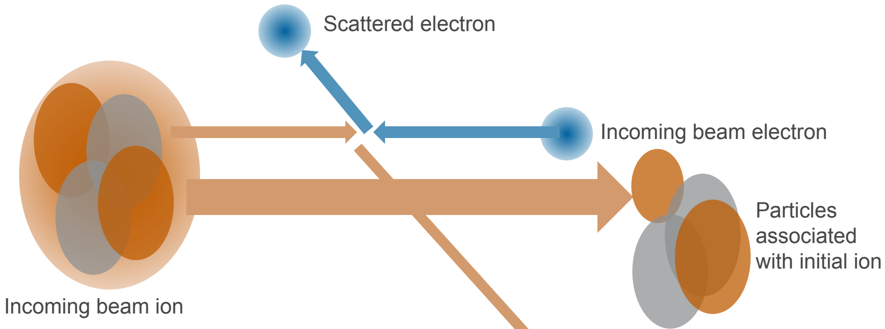
- Fine p_T resolution
- Extended PID systems for hadron identification
- Hadron calorimetry for jet physics

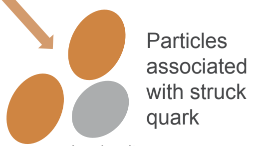
Exclusive processes require binning in four or more variables (x_B, Q^2, t, φ_h , …):

- Extend acceptance at extremely small scattering angles by far forward detectors
- Fine vertex resolution by tracking
- Highly granular EM-calorimeters to separate γ/π^0

Electron-Ion Collider: Accessing the Physics

Integrated detector/interaction region for near-full acceptance



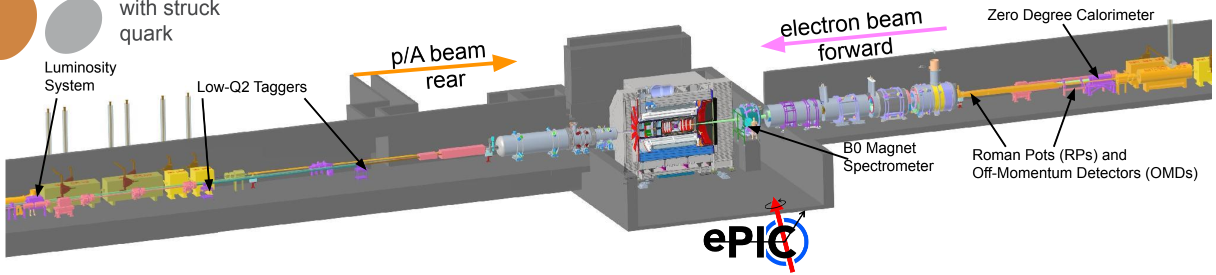


Experimental challenges:

- Beam elements limit forward acceptance
- Central solenoid not effective for particles with small deflection angles

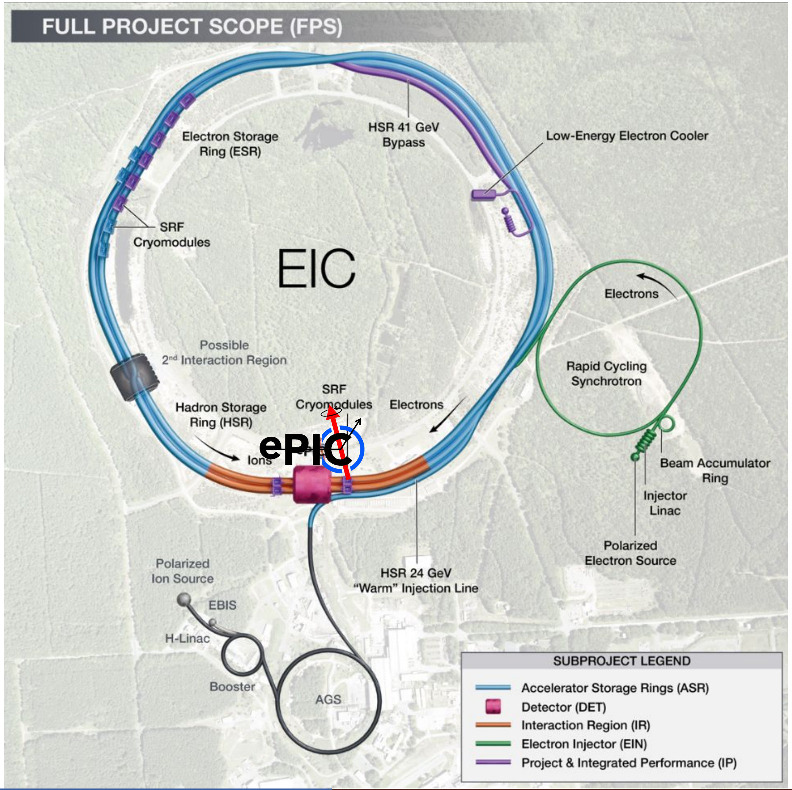
To achieve near-full acceptance :

- Beam crossing angle of 25mrad creates room for dipoles and Zero Degree Calorimeter
- Dipoles act as spectrometers and create space for detectors

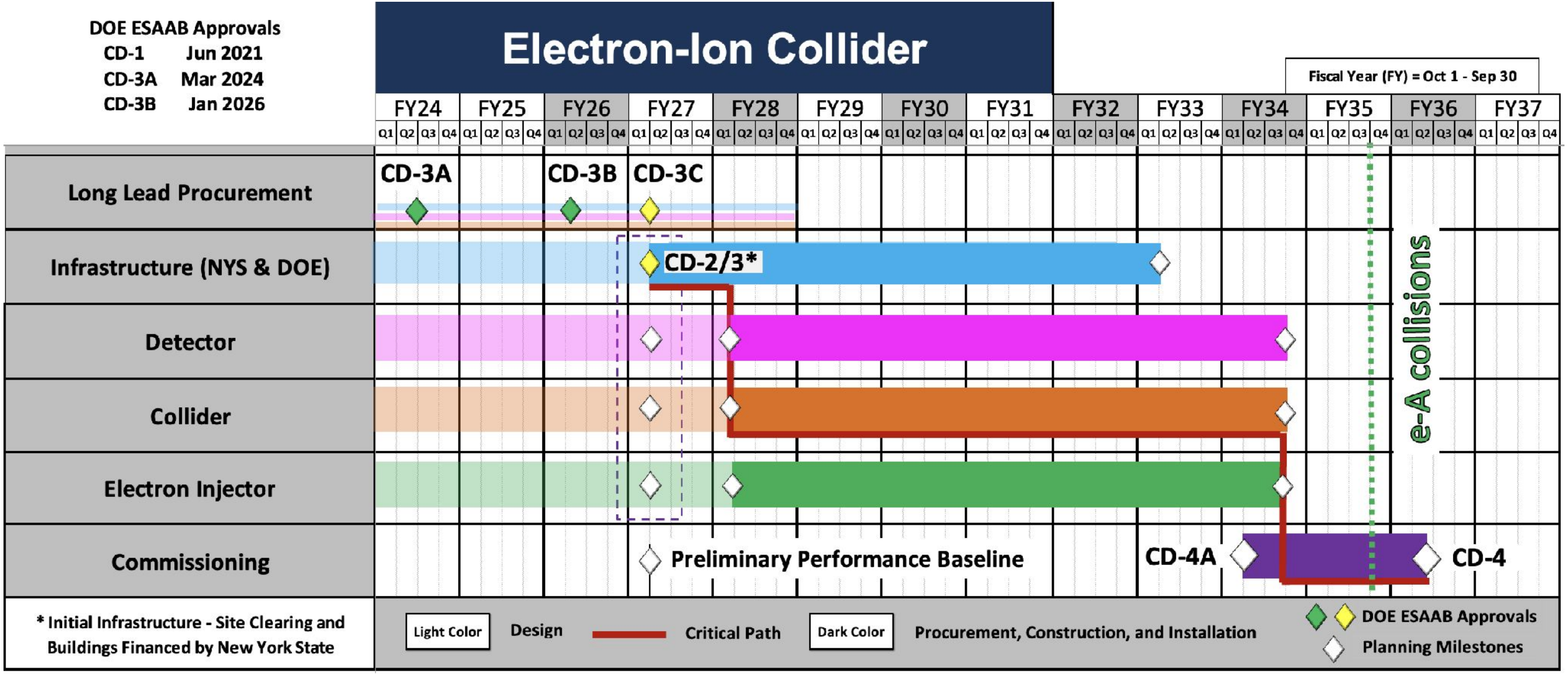


Electron-Ion Collider and ePIC Detector: Overview

- **First major collider** to be built in North America in the 21st century
  - **Polarized electrons**, 5-9(18) GeV
  - **Polarized light ions** (p, d, ^{3}He) and unpolarized nuclei → U, 40,100-250 GeV
  - Center-of-mass energy of 20-100(140) GeV
  - **High luminosity** $\mathcal{L}$ of 10^{33}–10^{34} cm^{-2} s^{-1}
- **International** facility with estimated cost of about US$3B
- **EIC User Group community** of 1500+ users, ~300 institutions, ~40 countries
- **ePIC collaboration** of ~1150 users, 183+ institutions, 26 countries
- **First collisions** in mid 2030s

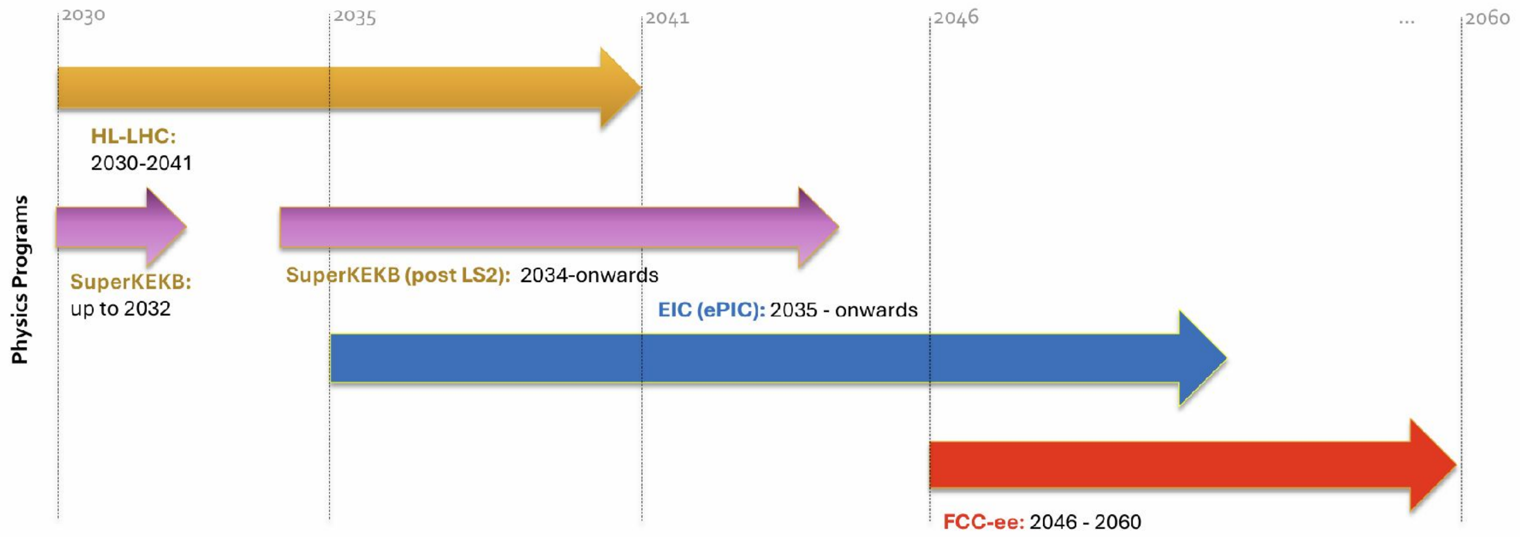


Electron-Ion Collider: Project Timeline



Note: this is a technically driven schedule, and may need to be adjusted for actual funding profile as it becomes better known.

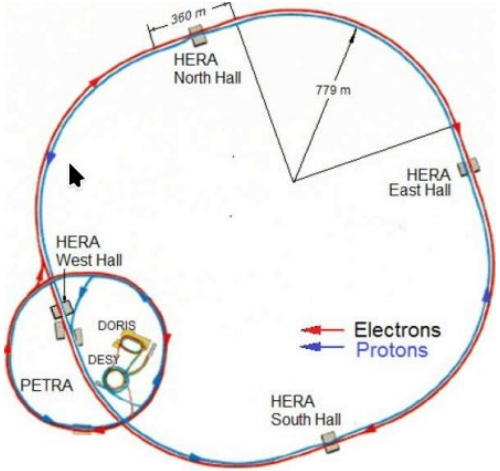
Electron-Ion Collider: Timeline in Global Context



- **Phasing of different colliders allows for global R&D with current experiments/machines driving the deployment of technology**
  - HL-LHC, SuperKEKB (HEP) →EIC (NP) → FCC (HEP)
- **Partial overlapping and staggered start-up times allow for cross-fertilization of physics results**
- **Gap in time between in HEP/NP colliders allows for a balanced effort between communities**
  - For example, scientists can analyze LHC data while preparing for EIC
  - Scientists (especially early career) will be able to do research at EIC while preparing for FCC
  - Provides continuous opportunities for training the next generation HENP technical workforce

Ref: John Lajoie, Joint APS DPF/DNP Meeting, https://indico.global/event/17474

Accelerator Development for the EIC



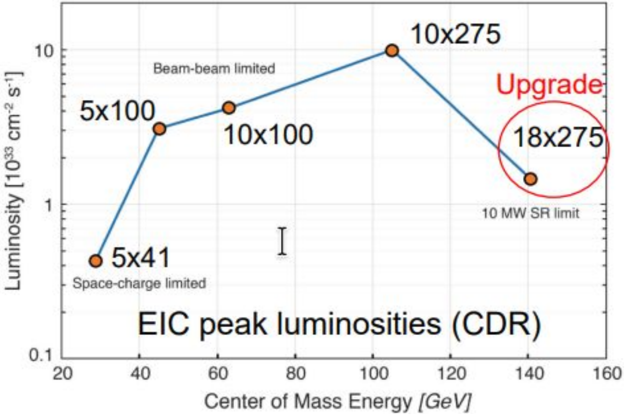
Key Accelerator Improvements

From **HERA**

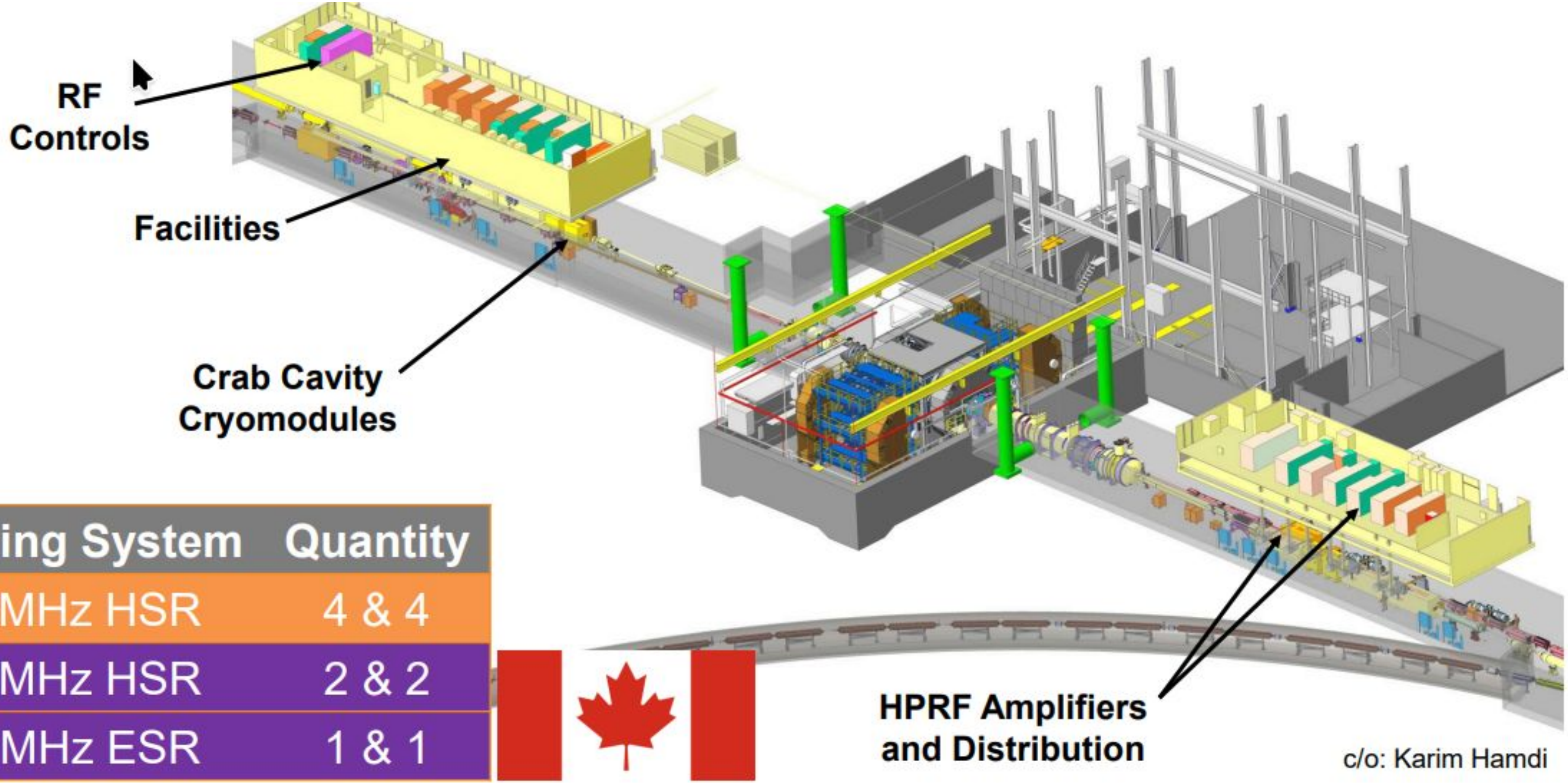
- 920 GeV protons (unpolarized)
- 27.5 GeV electrons (Sokolov-Ternov effect)
- Peak luminosity: ~5 × 10^{31} $cm^{-2}s^{-1}$, FOM ~ LP^2
- Center of mass energy: 318 GeV

to the **EIC**:

- Ion beam with proton/light ion polarization
- Both beams polarized from the source, FOM ~ LP^4
- Luminosity of 200 times higher, 10^{34} $cm^{-2}s^{-1}$
  - high bunch currents (e: 5.3→28 nC)
  - higher bunch counts (174→1160) in a smaller ring
- Variable center of mass energy from 20 to 100 GeV
- Wide ribbon-like beams; large crossing angle



Accelerator Development for the EIC: Crab Cavities



Crabbing System	Quantity
197 MHz HSR	4 & 4
394 MHz HSR	2 & 2
394 MHz ESR	1 & 1

Ref: Sergei Nagaitsev, June 2026 Resource Review Board Mtg, https://indico.bnl.gov/event/32211/

The ePIC Detector: Central Region

Magnet
- New 1.7 T SC solenoid, 2.8 m bore diameter

Tracking
- Si Vertex Tracker MAPS wafer-level stitched sensors (ALICE ITS3)
- Si Tracker MAPS barrel and disks
- Gaseous tracker: MPGDs (µRWELL, MMG) cylindrical and planar

PID
- high performance DIRC (hpDIRC)
- dual RICH (aerogel + gas) (forward)
- proximity focussing RICH (backward)
- ToF using AC-LGAD (barrel+forward)

EM Calorimetry
- imaging EMCal (barrel)
- W-powder/SciFi (forward)
- $PbWO_4$ crystals (backward)

Hadron calorimetry
- FeSc (barrel, re-used from sPHENIX)
- Steel/Scint – W/Scint (backward/forward)

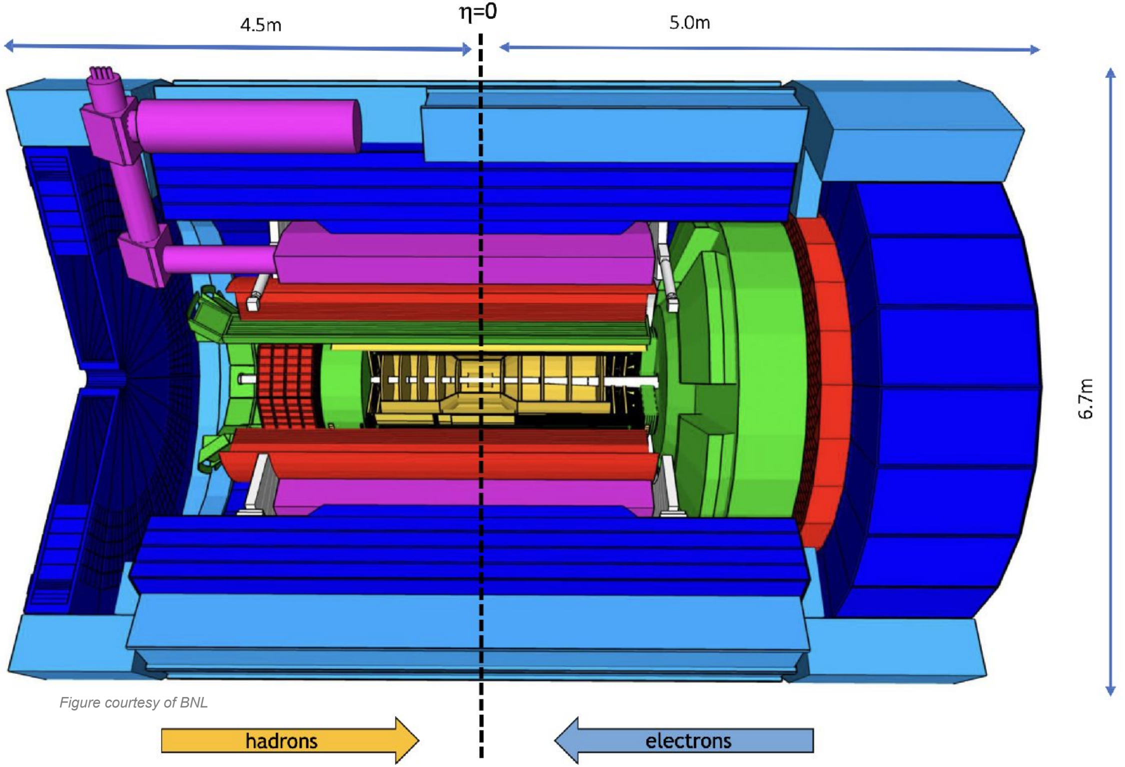
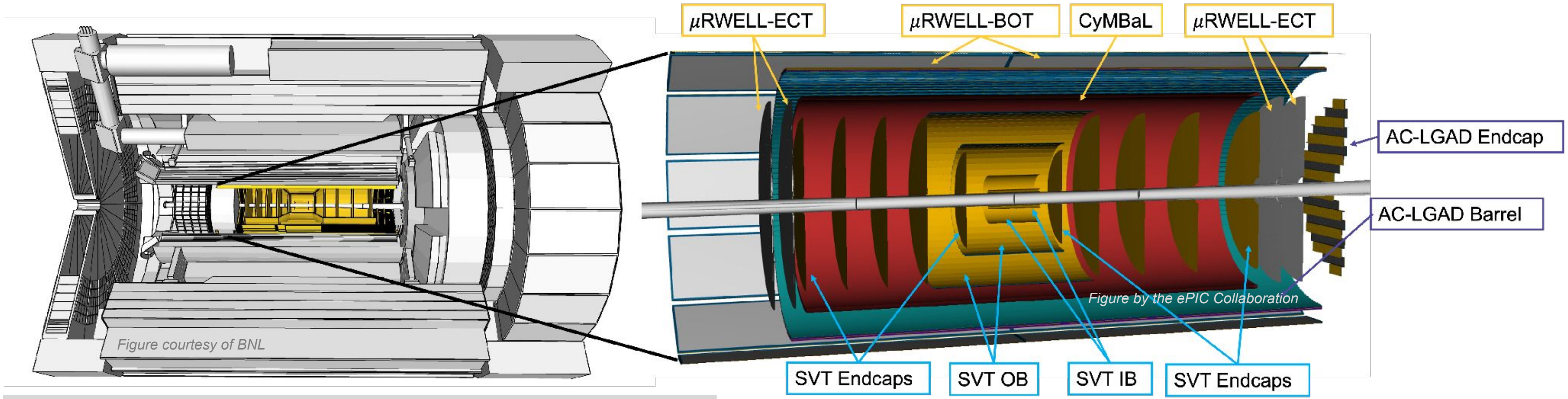


Figure courtesy of BNL

The ePIC Detector: Tracking Subsystems



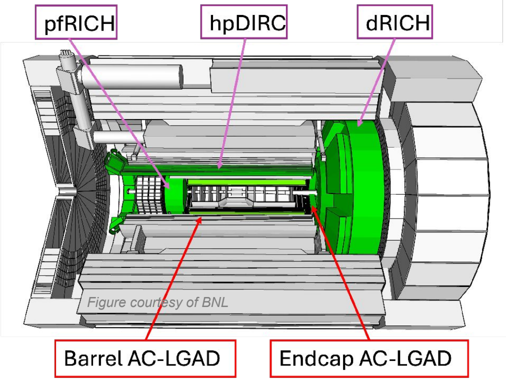
Tracking Requirements:

- High spatial resolution $20\mu m/p_T \oplus 5\mu m$
- Excellent momentum resolution $0.05\% p_T \oplus 0.5\%$
- Low material budget
- Good pattern recognition efficiency
- Sufficient time resolution to resolve 10ns bunch crossing
- Good angular resolution for the DIRC

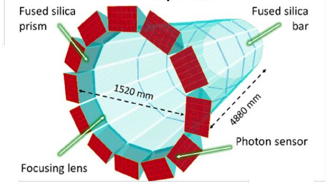
Detector Solutions

- Ultra-low-mass **barrel vertex tracker** using ALICE ITS3 curved MAPS technology, with 20µm pixel pitch and 0.05% X/X_0
- **Outer barrel and endcap silicon tracker** using new ITS3-based EIC Large Area Sensors (LAS), 20µm pixel pitch and 0.55% X/X_0
- **MicroMegas barrel tracker** (CyMBaL) with X/X_0
- **GEM-µRWell barrel and endcap tracker** with 10ns time resolution, 150µm spatial resolution and 1-2% X/X_0

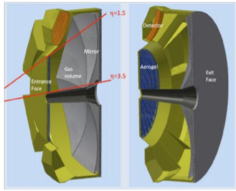
The ePIC Detector: Particle ID Subsystems



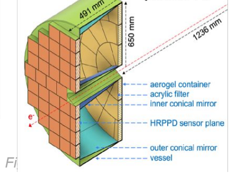
hpDIRC



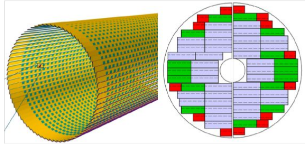
dRICH



pfRICH



Barrel AC-LGAD



Dual Radiator Ring Imaging Cherenkov (dRICH)

- Aerogel + C_2F_6 gas for high-momentum PID up to 50 GeV/c
- First-ever use of SiPMs in a RICH

Proximity Focusing RICH (pfRICH)

- Aerogel for PID up to 9 GeV/c
- First-ever use HRPPDs as photosensor □ 30ps time resolution for ToF

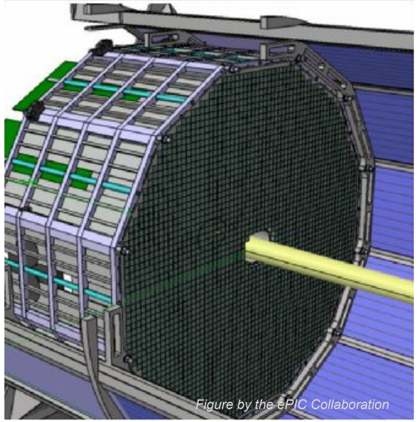
High-Performance DIRC Detector (hpDIRC)

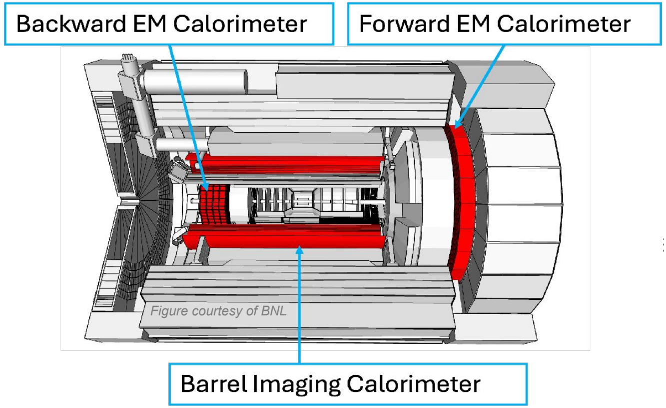
- Quartz bar radiator for PID up to 6 GeV/c
- Fully focused design with lens and large expansion volume
- Uses pixelized MCP-PMTs as photosensors

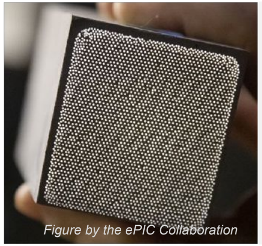
Time-of-Flight Barrel and Forward Endcap (BTOF and FTOF)

- AC-LGAD sensors give 20-35ps time resolution for ToF, for PID up to p_T < 1.5-2.5 GeV/c
- 500µm x 1 cm strips for BTOF (1% X/X_0) and 500µm pixel pitch for FTOF (2.5% X/X_0)
- Additional accurate space point and timing for tracking
- First-time use of AC-LGAD technology in a collider detector

The ePIC Detector: Electromagnetic Calorimetry







Forward Ecal

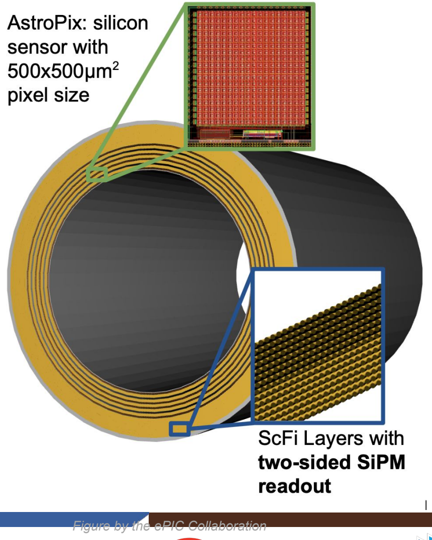
- W-powder/SciFi SPACAL design developed through EIC R&D and used in sPHENIX

Backward ECAL (EEEMCAL)

- High-precision $PbWO_4$ crystal calorimeter for precision scattered lepton measurements
- First use of SiPMs in a crystal calorimeter

Barrel Imaging Calorimeter (BIC)

- Hybrid imaging calorimeter: 6 layers of AstroPix sensors interleaved with 5 Pb/ScFi layers, followed by a large section of Pb/ScFi layers
- Pb/ScFi technology based on the GlueX design, using SiPMs for readout at either end of the barrel
- AstroPix: HV-MAPS sensor with 500µm pixel pitch and ~3.2ns time resolution developed for the NASA AMEGO-X mission.



The ePIC Detector: Barrel Imaging Calorimetry

High-performance sampling calorimeter with cost-effective Si sensors for shower profiling

Electromagnetic calorimetry in the barrel is difficult:

- Prime detector for **electron-pion separation**
- Need pion suppression up to 10^4 for inclusive physics
- Need **good photon resolution and granularity** to reject π^0
- Need **large dynamic range** from 100 MeV/c to well over 10 GeV/c while being sensitive to MIPs
- **Compact** – needs to fit in limited space inside of solenoid

The Barrel Imaging Calorimeter (BIC)

- The BIC is a novel imaging calorimeter designed to meet the stringent performance requirements essential for EIC science
- Combines mature, state-of-the-art Pb/SciFi sampling calorimetry with six layers of modern, ultra-low-power HV-MAPS AstroPix sensors
- The BIC will be **one of the largest silicon detectors ever built**, featuring over 100 m² of AstroPix sensors and marking the first large-scale deployment of HV-MAPS sensors for particle detection

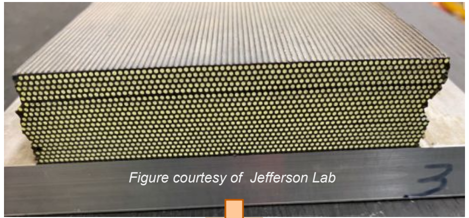


Figure courtesy of Jefferson Lab

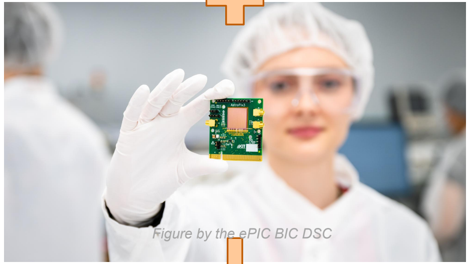


Figure by the ePIC BIC DSC

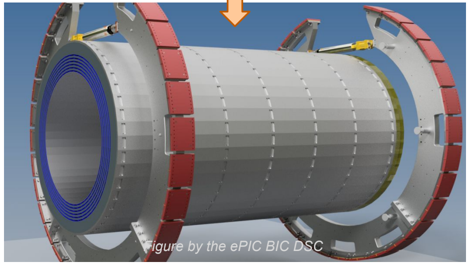
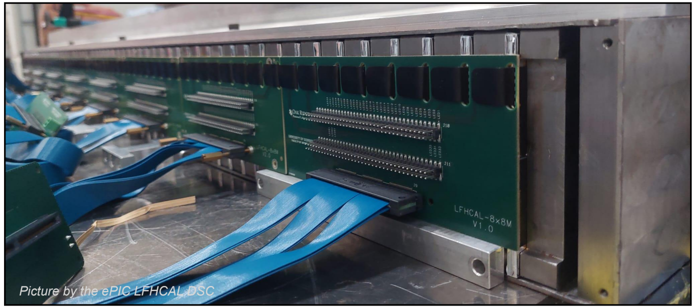


Figure by the ePIC BIC DSC

More info? Check out Maria Żurek's slides, Tuesday, June 23, https://indico.global/event/15553/sessions/20435/

The ePIC Detector: Hadronic Calorimetry



Forward HCAL (LFHCAL)

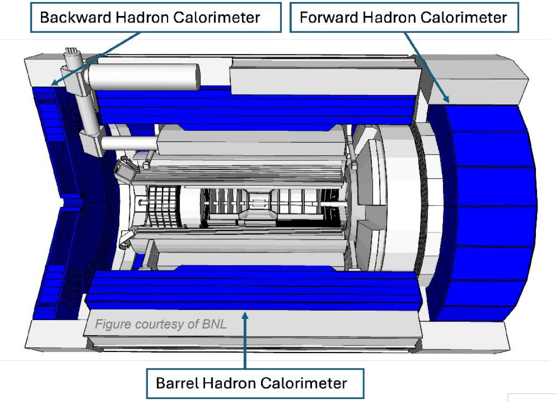
- Longitudinally segmented steel + scintillator SiPM-on-tile
- High-resolution insert next to beam pipe
- Optimized for particle-flow measurements, first full-size CALICE-like calorimeter in a collider experiment

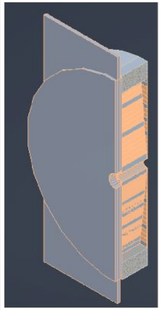
Barrel HCAL

- Steel + scintillator design, re-use from sPHENIX

Backward HCAL

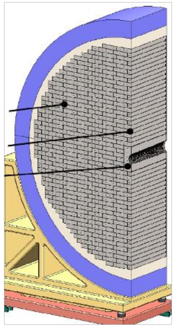
- Similar construction as LFHCAL, functions as tail catcher for EMCAL to improve jet energy reconstruction





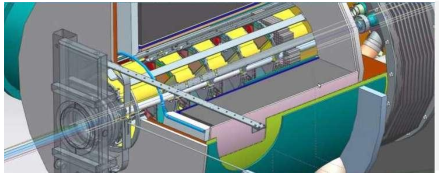
Backward Hadron Calorimeter

Barrel Hadron Calorimeter



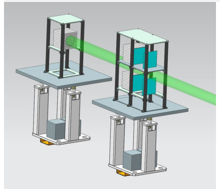
Forward Hadron Calorimeter

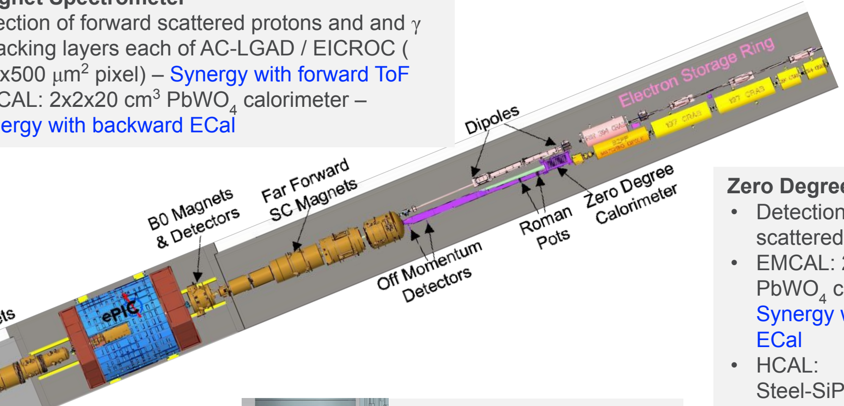
The ePIC Detector: Far Forward and Far Backward

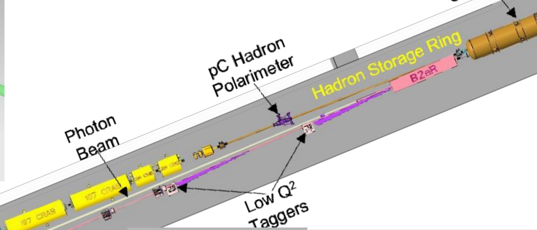


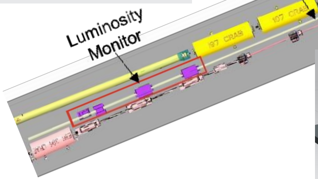
B0 Magnet Spectrometer
- detection of forward scattered protons and and γ
- 4 tracking layers each of AC-LGAD / EICROC (500x500 μm^2 pixel) – Synergy with forward ToF
- EMCAL: 2x2x20 cm^3 $PbWO_4$ calorimeter – Synergy with backward ECal

Luminosity System
- Measure bunch-by-bunch luminosity through Bethe-Heitler process
- Pair-spectrometer: each with 2 tracking layers of AC-LGAD / FCFD – Synergy with Barrel-ToF
- Calorimeter: Tungsten-powder + SciFi SPACAL – Synergy with forward ECal

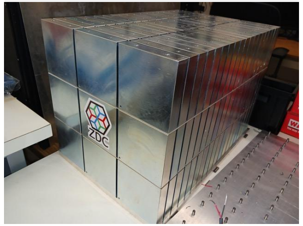


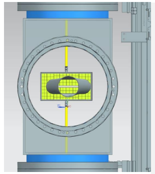




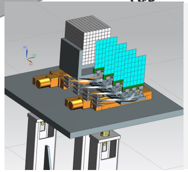


Zero Degree Calorimeter
- Detection of forward scattered neutrons and γ
- EMCAL: 2x2x20 cm^3 $PbWO_4$ calorimeter – Synergy with backward ECal
- HCAL: Steel-SiPM-on-Tile – Synergy with forward HCal



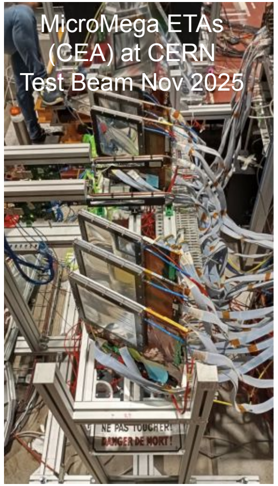


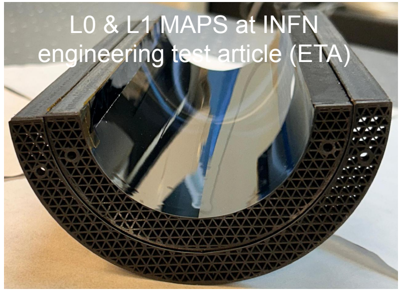
Roman Pots and Off-Momentum Detectors
- Detection of forward scattered protons and nuclei
- 2 stations with 2 tracking layers each
- AC-LGAD / EICROC (500x500 μm^2 pixel) – Synergy with forward ToF

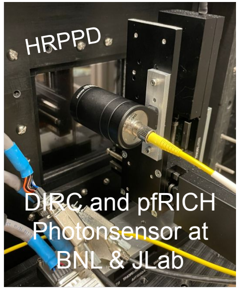


Low-Q^2 Taggers
- detection of scattered electrons
- 2 stations with 4 tracking layers each ($16x18cm^2$) Si / Timepix4
- Calorimeter: Tungsten-powder + SciFi SPACAL – Synergy with forward ECal

Figures courtesy of BNL

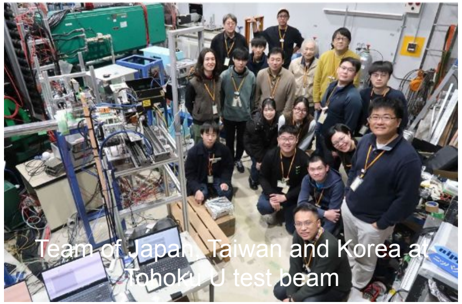

MicroMega ETAs (CEA) at CERN Test Beam Nov 2025


L0 & L1 MAPS at INFN engineering test article (ETA)

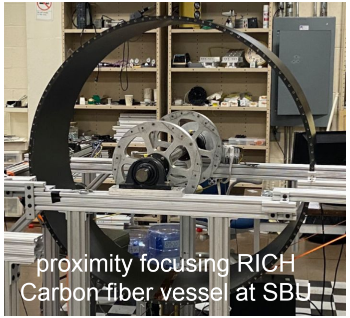

HRPPD

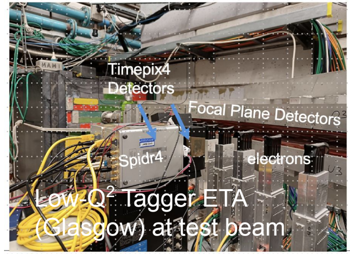
DIRC and pfRICH Photonsensor at BNL & JLab


µRWELL-ECT ETAs (INFN) at CERN Test Beam 11/25

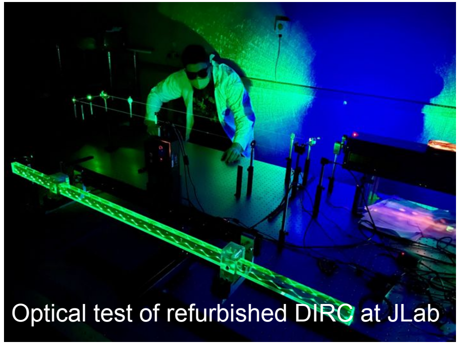

Team of Japan, Taiwan and Korea at Tohoku U test beam

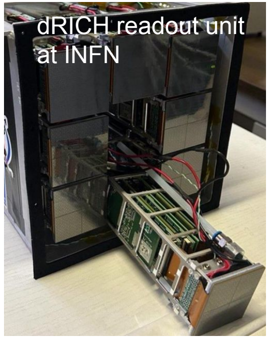

ePIC DAQ Setup at BNL (similar at JLab)

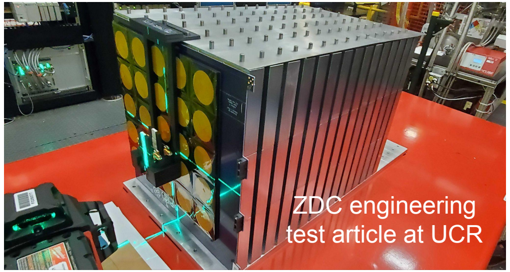

proximity focusing RICH Carbon fiber vessel at SBU



Low-Q^2 Tagger ETA (Glasgow) at test beam


Optical test of refurbished DIRC at JLab


dRICH readout unit at INFN


ZDC engineering test article at UCR


forward HCal engineering test article at CERN test beam

Computing Development for the EIC

Streaming Readout and Distributed Heterogeneous Computing

Streaming Readout and DAQ:

- High-speed data flow: Front-end electronics designed to support total bandwidth of up to 50 Tbps, with streaming of 100 Gbps to storage.
- Zero dead time: No traditional hardware trigger for unbiased data collection in timeframes of 667 μs. Zero-suppression at channel or front-end board level.

AI and ML in the data pipeline:

- Intelligent data filtering: AI/ML algorithms to filter most relevant collision events to study
- Real-time feedback and control: systems for automatically calibrating detectors and validating data.

Collaborative Community Software:

- Strong alignment with HEP and FCC tools built around key4HEP

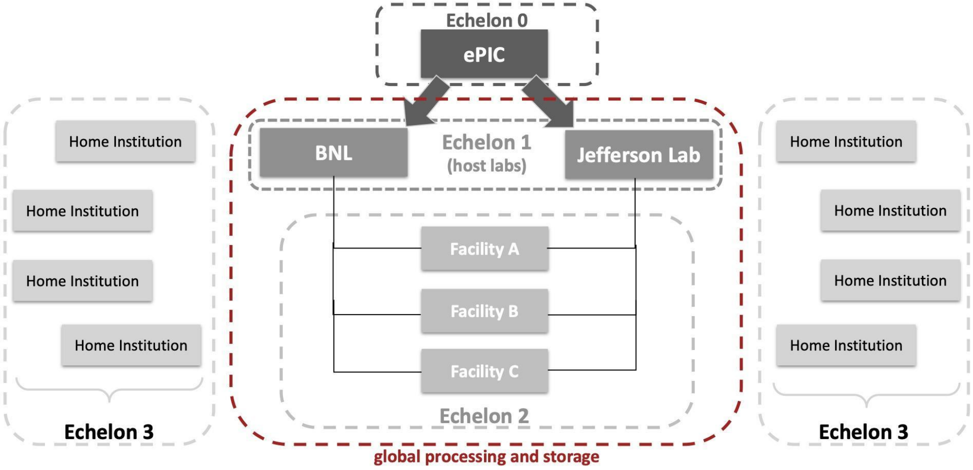
Computing Development for the EIC

Streaming Readout and Distributed Heterogeneous Computing

Streaming Computing Model (https://zenodo.org/records/14675920):

- Continuous calibration and alignment: rapid delivery of scientific results
- Echelon model: organizes resources across the computing hierarchy and enables international contributions; alignment with WLCG and LHCONE

First prototype echelon 2 site commissioned in Canada! (June 2026)



Early Science Program at the EIC

Year - 1

Potentially Run:
9 GeV electrons on 115 GeV/u heavy ion beams (Ag, Ru or Cu)

Commission:
electron polarization (in parallel)

Year - 2

Potentially Run:
9 GeV long. polarized electrons on 130 GeV/u Deuterium

Last weeks 9 GeV long. polarized electrons and 130 GeV polarized protons

Commission:
proton polarization (in parallel)

Year - 3

Potentially Run:
9 GeV long. polarized electrons on 130 GeV transverse polarized protons

Commission:
Commission running with hadron spin rotators.

(Last weeks switch to longitudinal proton polarization?)

Year - 4

Potentially Run:
9 GeV long. polarized electrons on 100 GeV Au

9 GeV long. polarized electrons on 275 GeV transverse and longitudinal polarized protons

Commission:
Commission hadron accelerator to operate with non-centered orbits

Year - 5

Potentially Run:
9 GeV long. polarized electrons on 100 GeV Au

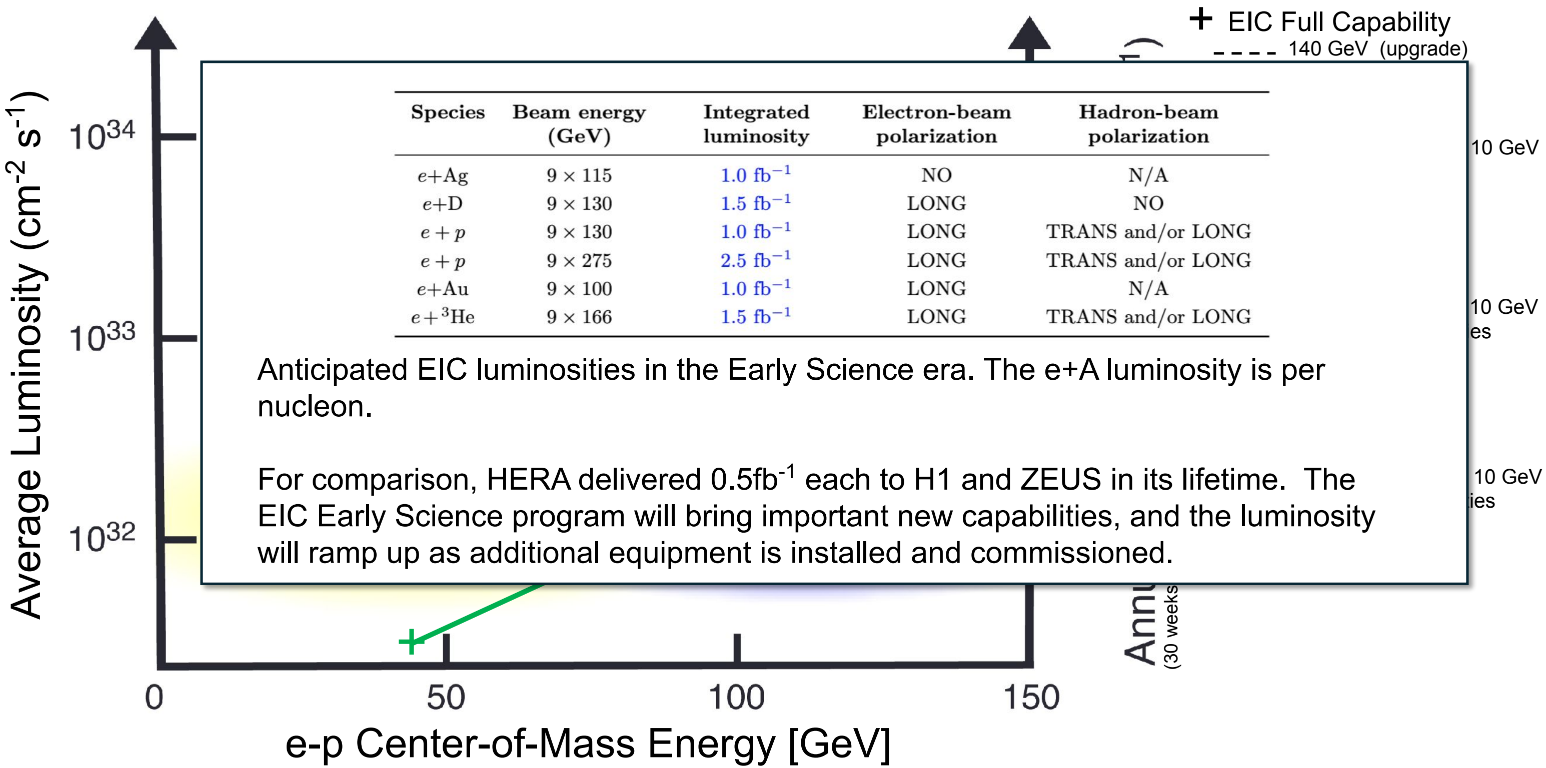
9 GeV long. polarized electrons on 166 GeV transverse and longitudinal polarized He^3

Run plans notional but based on commissioning of the EIC collider capabilities

Time to install additional equipment to reach design current, luminosity and maximum energies

Note: 9 GeV electrons allow 10nC/bunch (vs 7nC/bunch at 10 GeV) with limited SRF in ESR

EIC Science Reach for ep

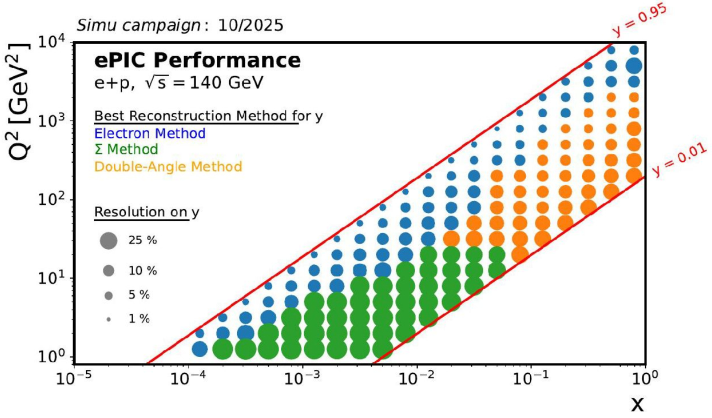


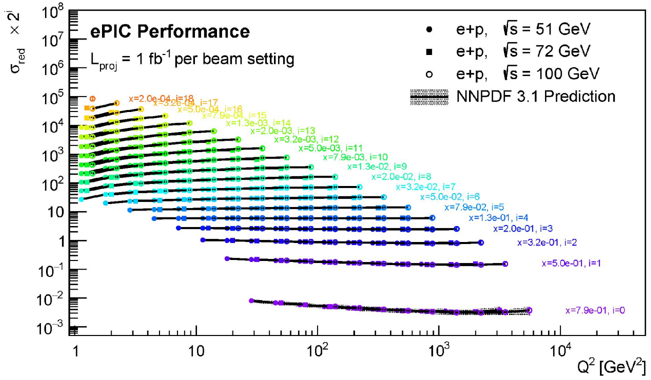
Species	Beam energy (GeV)	Integrated luminosity	Electron-beam polarization	Hadron-beam polarization
e+Ag	9 × 115	1.0 fb^{-1}	NO	N/A
e+D	9 × 130	1.5 fb^{-1}	LONG	NO
$e+p$	9 × 130	1.0 fb^{-1}	LONG	TRANS and/or LONG
$e+p$	9 × 275	2.5 fb^{-1}	LONG	TRANS and/or LONG
e+Au	9 × 100	1.0 fb^{-1}	LONG	N/A
$e+{}^{3}$He	9 × 166	1.5 fb^{-1}	LONG	TRANS and/or LONG

Anticipated EIC luminosities in the Early Science era. The e+A luminosity is per nucleon.

For comparison, HERA delivered 0.5fb^{-1} each to H1 and ZEUS in its lifetime. The EIC Early Science program will bring important new capabilities, and the luminosity will ramp up as additional equipment is installed and commissioned.

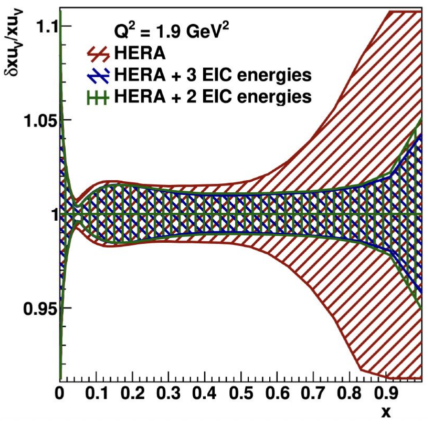
EIC Early Science Reach Highlight: Proton PDFs

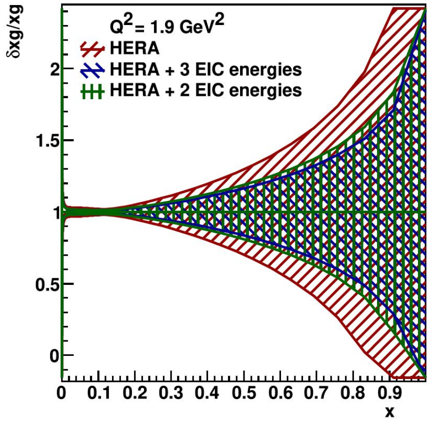




Using various inelasticity methods (electron, Sigma, or DA): better than 30% resolution for full x-Q^2 acceptance (and better anticipated with AI/ML methods).

Reduced uncertainties on PDFs projected, in particular at high x.



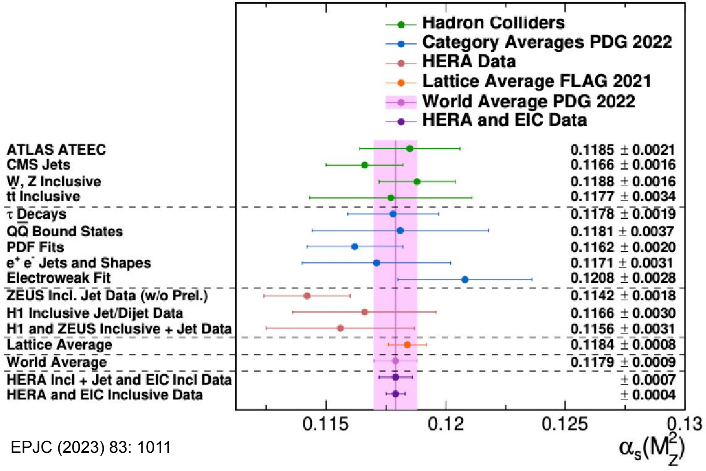


Ref: arxiv:2602.00860, "Inclusive electron-proton measurement prospects in the Electron-Ion Collider early science stage."

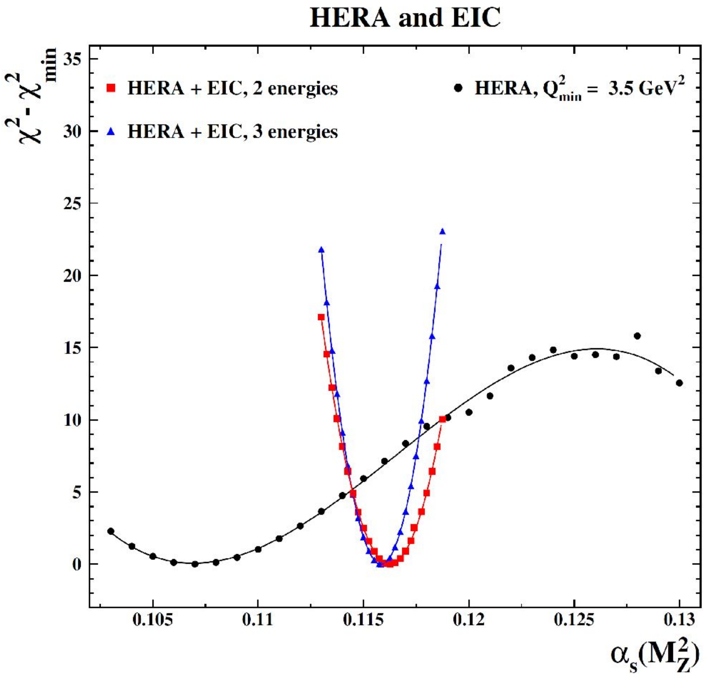
EIC Early Science Reach Highlight: Proton PDFs

Projected Determination of α_s

HERA data alone shows only limited sensitivity when fitting inclusive data only. Adding EIC (precision high x) can lead to a precision a factor ~2 better than current world experimental average, and lattice QCD average.



EPJC (2023) 83: 1011



Ref: arxiv:2602.00860, "Inclusive electron-proton measurement prospects in the Electron-Ion Collider early science stage."

Canadian Participation in the EIC

Multiple intersecting research programs with 10+ active PIs

Infrastructure design and development:

- Superconducting RF Crab Cavities (CFI IF 2026-2031): TRIUMF, U. Victoria
- Barrel Imaging Calorimeter End-of-Sector Boxes (CFI IF 2026-2031): U. Regina, U. Manitoba, Mt. Allison
- Software/Computing/AI: U. Manitoba, U. Regina

Physics research and analysis:

- Heavy and light quark spectroscopy: U. Regina
- Meson form factors: U. Regina, Mt. Allison
- Precision standard model tests: U. Manitoba
- Spin polarization electroweak observables: U. Manitoba

Software/Computing/AI: U. Manitoba, U. Regina

Prospective new PIs welcome! Talk to us!

Outlook

Over the next decade, the EIC will build and commission accelerator systems, detectors and software towards first collisions in the mid 2030s.

Already, several international HEP groups have joined EIC and ePIC efforts, including in areas of silicon tracking sensors and high granularity calorimetry.

While not at the energy frontier, we believe that these synergies make the EIC a potentially valuable proving ground of new techniques while the FCC design is finalized.

University of Manitoba